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THE CAUSAL RELATIONS BETWEEN STRUCTURE AND FUNCTION IN BIOLOGY

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In a not very wide search through the possible literature the writer has been unable to find a solution of the problem indicated by the title of this paper. That he is not the only one to whom it has been more or less of a puzzle is evident from some comparatively recent discussions in medical and other societies. In one it was said "The question of the relation of structure to function is the great biologic problem," the speaker stating that "function determines structure just as in its turn structure determines, delimits—that is, places definite limits on function,"¹ but without further elucidating the relationship.

Does structure determine function, or does function determine structure, or does each determine the other, and if the latter, how can it be?

The answers to these questions seem to the writer to be matters partly of definition, partly of point of view, and partly of the recognition of purpose in Nature.

In the inorganic world structure may be regarded merely as the mechanical collocation of parts in a whole. The pile of sand has structure in this sense. But in the biologic world, and in all structures made or used by man, structure is a mechanical collocation of parts *adapted to an end*. Structure then becomes a machine, an organ, a mechanism as a means to an end. Though there are some who still try to explain all vital (including psychic) phenomena on a basis of mere mechanical cause and effect, and think they succeed, the majority hold with Kant that efficient causes alone are not sufficient to explain the facts of organic life, and that final causes are essential to the explanation and that they belong to a different series.

In the so-called exact sciences—mathematics, chemistry, physics, astronomy—the question of end and means does not arise; or if, as in applied physics, it does arise, it takes the

¹ Dr. W. Ophüls, *Anatomic Structure and Function*, *Jour. A. M. A.*, Vol. 63, p. 521.

form of man's devising means to attain his own definite conscious ends or purposes.

But in the biological sciences it is not so obvious who conceives the end that is to be served. Personally the writer feels forced to the conclusion that all Nature—the universe as a whole—is a personality whose total end is the perfection of all its parts; that to this end the development in each evolving part, or biological unit, of mechanisms which enable this part to adapt itself better and better to its environment is an essential means; and therefore that it is Nature itself—the universal personality—which has conceived the ends which are served by biological mechanisms, whether physical, psychological or ethical.

Not only universal ends but also those of the biological unit are served by these mechanisms. But it was not the individual unit that conceived the ends to which its structure is adapted. Having the structure, however, the individual may use it for its own conscious ends, where evolution has advanced far enough for it to formulate them. So rarely in biology do we see structures that are not adapted to ends, that when we happen upon a new structure we inevitably ask what its purpose may be. As a matter of course we assume that it serves *some* purpose. Hence we are justified in defining structure in biology as *a mechanical collocation of parts adapted to an end*.

In the biological sciences the word *function* is used in connection with the *activity* of some structure or mechanism; and, since structure or mechanism involves an end, function has to do with *activity directed to an end*. This expresses an actual or potential relation between two terms, a something which acts or is capable of acting, and a something which is done or is to be done. This relation may be regarded from the point of view of one term or of the other—actively from the point of view of the doer, i. e., structure, *agens*, or passively from that of the thing to be done, *agendum*.

When, for example, we say "it is the function of the stomach to digest food," we use the word from the point of view of the stomach as agent, *agens*. In this case function means *activity directed to an end*, and it expresses the relation between the terms—the doer and the end.

But when we say "food is to be digested, and that is the function of the stomach," we use the word from the point of view of the thing to be done, *agendum*. In this case function

means *an end toward which an activity is directed*, and it therefore expresses but one term of the relation.²

In many instances it is immaterial which meaning of function we have in mind—the context makes us automatically choose the appropriate one. But when the two meanings are brought into contrast, with only the one word to use for the two meanings, as in considering the causal relationships between structure and function, confusion inevitably arises, unless we keep clearly in mind that there *are* two meanings. With this difference in mind we can approach the problem of whether structure determines function, or vice versa, or if both are true.

Structure being a mechanical collocation of parts adapted to an end, it is obvious that it cannot act, i. e., serve that end, unless it already exists. The stomach must exist before it can digest food, i. e., perform its function in the sense of activity directed to an end. The structure of the stomach, whether a mere body cavity as in the "gastrula" or the highly complex organ of some of the higher animals, will determine the way in which food is digested. That is, in the actual performance of its function, the structure of the organ will determine how the thing is done. *Mechanically*, therefore, that is, in the cause-and-effect series, *structure* precedes, or *determines*, or is a cause of *function*.

But on the other hand, it is the end toward which an activity is to be directed (*agendum*) that will determine what sort of a mechanism is required. If a tree is to be felled, we do not attack it with a pencil, but with something—axe or saw—that will tear or cut its tissues. It is the nature of the food stuffs to be digested that determines the character of the organs and processes necessary to digest them. If our food had been iron, and oxidation necessary for its use, the structure of our stomachs would have been of such a character as to oxidize iron. In other words, in the development of organs, structure, or mechanism, for the performance of certain functions, the nature of the thing to be done, i. e., the function in the sense of end to which an activity is directed, will determine to some extent the structure. *Teleologically*, therefore, that is, in the end-and-means series, *function* precedes, or *determines*, or is a cause of *structure*.

When Spencer says "Everywhere structures in great measure determine functions; and everywhere functions are in-

² For the needs of the present argument it is not necessary to subdivide the ends as Ruckmich does (*Am. Jour. Psychol.*, Vol. 24, p. 99 sq.).

cessantly modifying structures,"³ he states a seeming paradox which is easily soluble if we paraphrase it, in accordance with the above distinction, "Everywhere mechanical collocations of parts adapted to ends in great measure [mechanically] determine the activities directed to [those] ends; and everywhere ends toward which activities are directed are incessantly [teleologically] modifying the mechanical collocations of parts adapted to [those] ends."

Thus it is seen that each proposition is true, but in a different sense. It is only teleologically that function determines structure, and only mechanically that structure determines function. In neither case is function or structure the *sole* cause of the other. And in no case can either structure or function or the relations between them be wholly understood on mechanical or on teleological grounds alone.

The value of a principle lies in its application. The application of the principle involved in the foregoing discussion has been of fundamental value to the writer (and hence it may be to others) in approaching the problem of mind, the subject-matter of psychology which he regards as one of the biological sciences—biology being conceived as the science of living things rather than as the science of matter in the living state.

So far as our experience goes mind is manifested only by living things, and by them as internal activities or reactions of individuals. These reactions are made in the course and for the purpose of the self-adaptation of the individual to his environment. The nature of the environment then will partly determine, as final cause, what kinds of activities the individual shall be capable of, i. e., what general types of reaction he must make, and hence the structures and mechanisms for making them.

This is obvious when we regard such reactions as those of seeing, hearing, etc. The physical nature of light and color as a mode of energy has determined, as final cause, the general nature of the organ which shall be sensitive to or stimulated into activity by it. Equally obviously the actual structure of the organ sensitive to light in any given biological unit, whether the red spot of the star fish or the eye of man with its nervous connections, will determine, as an efficient cause, the extent and completeness of the reaction made by that unit. Since every individual is finite, no reaction can be absolutely complete.

³ Principles of Biology, Vol. II, p. 4.

It is less obvious, though in the writer's belief not less true, that there are in the environment not only things, but *kinds* of things, the actual kind consisting of *all* the past and present individuals of the kind—all the specimens of the species. The existence of kinds as actual objective realities or factors in the environment is a determinant, as final cause, of the capacity of the individual to form *concepts*, and hence of the structure which subserves this function. The mechanism of this function is still obscure; the structure or organ is doubtless some part or parts of the brain. Since no individual can experience all the specimens of any given kind of thing, the concept which he forms will be in part determined, as efficient cause, by the number and variety of the specimens that he has experienced, and in part by the extent of his capacity to react in this particular way; this capacity being in turn efficiently determined by the structure of the brain. Our concept of any particular kind of thing or event grows or is modified by additional experiences of things or events of that kind, up to the point of our capacity to enlarge or modify our concepts. The feeble-minded person has very limited capacity, the scientific genius very great capacity, in this respect.

Similarly, in the writer's belief, it is equally true that there are *relations*, not only spatial and temporal, but of many other kinds; and that there are many types or kinds of *law* or *necessity*; and many kinds of *obligation* or *duty*; and that because these are all actual objective realities existent in the environment, they have been final causes of the development of mechanisms and structures for the purpose of enabling the individual to adjust himself to them as factors of the environment.

There is very greatly needed, for psychology especially, a study of the environment, not only as a particular efficient cause for individual reactions of given types in given situations and circumstances, but as a general or final cause for the evolution in the individual of the capacities to react in all the ways in which it does react and of the mechanisms and structures for this purpose. For example, for us human beings obligation is a very important factor in our environment, in consequence of which a capacity for forming moral concepts has been evolved in us. What types of obligation are there? To which of them does this or that person react, or can he react? Can or do any of the lower animals react to them, and if so, to which? Have any mechanisms been evolved in them for this purpose?

If we would fully understand comparative psychology and

animal behavior, we must know what factors of the environment the animal is capable of reacting to, and what the *whole* situation is to which it is reacting, as well as the reaction itself in any given experiment or observation. The same is true of human psychology and behavior. In the study of pathological psychology the factors which affect the structures that subserve these functions and modify their mechanisms must of course also be considered; in normal psychology they may be largely taken for granted. It may be added that a comprehensive study of the nature of the environment—an ontology—must of necessity lie at the foundation of a thoroughly scientific theory of knowledge, and becomes essential if we would fully understand some of the differences between knowledge on the one hand and ignorance, error, delusion and hallucination on the other.